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Analysis of Rainfall and Temperature Trends and Their Implications on Green Gram Production in the Arid and Semi-Arid Lands of Kenya

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Abstract

Farmers have been facing numerous challenges in the production of green gram with declining yields being the main challenge. This can be attributed to the declining rainfall amounts and unreliable rainfall patterns, increased temperatures and high infestation of the crop by pests and diseases. In this study, climate data of the Makueni County on rainfall and temperature from 1991 to 2020 were obtained from the Kenya Meteorology Department. The data were analyzed in three sets; monthly, annual-monthly and seasonal time series. The analysis focuses on descriptive statistics and trend analysis. The results showed that there was no significant trend in the rainfall data at all three levels; monthly, annual-monthly and seasonal. The absence of a significant trend was associated with the high variability in the time series; hence, instability and unpredictability. The temperature time series exhibited positive linear trends where the maximum temperature increased by 0.003°C and the minimum temperature increased by 0.001°C per month. Such trends were detected in selected monthly as well as seasonal minimum and maximum temperature time series. The unpredictability of rainfall patterns and consistently but gradually rising temperature levels could be attributed to climate change. The crop optimum growing conditions are not attained, therefore, reducing production. Rapid deployment of integrated climate-smart farming techniques and adaptation strategies in the region is recommended for the green gram value chain to build resilience in the production of green gram to achieve sustainable yields.

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Introduction

Green gram farming plays a key role in the economy of the arid and semi-arid lands of Kenya such as Makueni County. It contributes to the socio-economic well-being of the people among other important value chain commodities like poultry-rearing, mango-growing and livestock keeping [1]. However, the effects of climate change have in recent times hampered the production of the crop, leading to great losses. The climate in Kibwezi East Sub County in Makueni County Kenya where this study was conducted is characterized by extreme rainfall variability and high temperatures. This phenomenon results in prolonged droughts from time to time, which affects crop production. The high temperatures in the low-lying areas cause high evapotranspiration that limits plant growth and leads to low crop yields in most of the seasons. The net effect of all this is failed crops; hence, food shortages. According to a study conducted by the Ministry of Agriculture, Kenya in 2016, the changing climatic conditions have affected crop production in Makueni County. For instance, maize yields have been declining rapidly since 1994. Maize is a staple food crop in this area. In 2013, there was a 70-90% crop failure in the County in major crops like maize, cowpeas and green grams. Cowpeas had a 74% drop and green gram registered a 79% decrease in productivity [2]. Recent reports by the Ministry of Agriculture indicate that there was a decline in yields from 460 kg/ha in 2010 to 380 kg/ha in 2013. The yields are lower than the global average of 730 kg/ha. Green gram farming plays a key role in the economy of Makueni County. It contributes to the socio-economic well-being of the people among other important value chain commodities in the area because it requires less rainfall than maize, resists drought and matures early. Therefore, many farmers have gradually abandoned maize farming for green grams [1].

Green gram (*Vigna radiata* L. Wildzek*)* is a leguminous crop of the species *Vigna* and is native to the Indian subcontinent. Worldwide, the crop is cultivated in hot and dry regions of Southern Europe, Southern United States and Eastern Africa. In Kenya, the crop is mostly grown under rain-fed conditions. Annually green gram contributes an average of Kshs 32 billion to Kenya's economy. The national total production of green grams in the last few years has been ranging from 61,000 MT to 121,000 MT [3]. Over the last 5 years, there has been an increase in the area under green gram production by 61% from 188,000 ha in 2012 to over 302,000 ha in 2017. This can be attributed to the expansion of green gram production to non-traditional green gram growing areas due to climate change [4]. Some of the areas that have been relatively cold and have not been able to support green gram production have become warmer and can support the production of the crop [5]. Over the same period, national consumption has grown from 58,000 MT to 127,000 MT implying that there exists a deficit that is bridged through imports [3]. The crop has existing and emerging market opportunities regionally and internationally, especially in India and South Asia [6]. The increasing demand for green grams is driven by a growing population, the opening of export markets abroad, rising international prices compared to other comparable legumes as well as dietary changes and preferences. A study done by the Kilimo Trust to characterize the green gram end markets in East Africa showed that Kenya had a deficit of 17,124 MT of green grams in the year 2014. It further stated that from a regional perspective, Tanzania and Uganda produce surpluses while Kenya is always a deficit Country [6].

Green gram also known as *Mung bean* or *Moong* in Hindi is a food and cash crop in Kenya and plays a key role in supporting the livelihoods of farmers as an income-generating agro-enterprise [4]. The legume matures quickly and is well adapted to the ASALs. It is the hardest of all pulses and adaptable to a wide range of climatic conditions [7]. The crop is well adapted to well-drained loam to sandy loam soils and does not do well in saline, alkaline and water-logged soils. The optimum pH of the soil is 5.5 to 7.5 [8]. The average annual rainfall requirement is 350-700 mm which should be evenly distributed during the growing season. The optimum temperatures for growing green gram range from 25°C to 30°C. The crop requires adequate soil moisture during the active growing period and especially from flowering to early and late pod-filling stage. According to Masaku [9], high humidity and excess rainfall in the later stages of the crop cycle may lead to increased disease and insect problems. This can result in crop damage, delayed maturity, rotting, poor yield and increased cost of production. However, with the changing climatic conditions in those areas, ways of sustaining production of the crop are needed in order to cushion the farmers against climate shocks [10]. According to a study done by USAID-KAVES [11], farmers mostly intercrop green gram with maize, sorghum or millet. In some instances, they plant pure stands of green grams. In Kenya, the yields have declined and most farmers generally harvest 1-2 bags of 90 kg per acre.

As interest in the crop is growing, several researchers including Muthukumar and Sulaiman [12], and Prasad [13] have urged farmers to adopt simple farming techniques that can increase the yields to 10 bags per acre. Consequently, the area under green gram production has increased by 61% over the last 5 years. However, ways of increasing and maintaining yields are needed to build resilience to the changing climate conditions as well as to meet the high demand in the local and international markets. Climate change amplifies the frequency and severity of droughts. Droughts are characterized by high temperatures and low rainfall amounts. These conditions interfere with plant growth and ultimately affect the quantity and quality of yields [5]. Temperature trend analysis by SNV [5] from 1961 to 2005 in the March, April, May (MAM) and October, November and December (OND) rainy seasons showed that temperature has been increasing by more than 1°C per decade in most of the green gram growing areas in Kenya. Climate projection was also done by SNV CRAFT [14] for Kenya, Uganda and Tanzania using high resolution data from Coordinated Regional climate Downscaling Experiment (CORDEX) downscaled from four Global Circulation Models (GCMS). This projection used the RCP scenarios 4.5 and 8.5 mid and high-level emission scenarios. It showed that the temperature in the MAM and OND rainy seasons is expected to rise by about 1.4°C to 1.8°C and 2.4°C to 2.8°C in the 2030s and 2050s, respectively. A projection model done using the business-as-usual scenario showed that temperature in the 2050s is expected to rise by about 2.3°C to 2.8°C and 2.0°C to 2.4°C in the southeastern and western areas of Kenya, respectively, during the two rainy seasons. Yields can be relatively increased by the use of innovative Climate Smart Agriculture (CSA) practices, which are ecologically friendly. Similarly, Reddy et al. [15] argued that CSA practices would go a long way in increasing yields sustainably, helping in adaptation to climate change and mitigating its effects. The adoption of CSA goes hand in hand with the use of innovative technologies as well as effective communication of weather and climate information to farmers [4].

Materials and Methods

Study area

The study was carried out in Makueni County, Kibwezi East Sub County. The county lies between Latitude 1º 35´ and 3 º 00 South and Longitude 37º10´ and 38º 30´East Kenya. The land area cover of Makueni County is 8, 034.7 Km^2 [2]. It is divided into six sub-counties, namely; Kaiti, Kilome and Mbooni in the upper region and Makueni, Kibwezi East and Kibwezi West in the mid and lower regions. The area of study has four wards; Mtito Andei, Masongaleni,

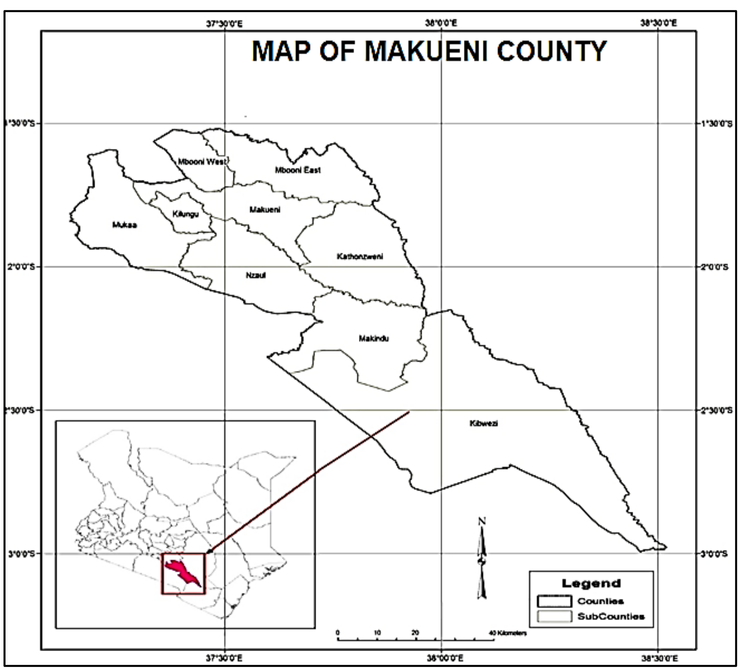

Fig. 1 Map of Makueni County. Source, Kenya Bureau of Statistics; Source: KNBS (2020).

Thange and Ivingoni. Farmers here grow crops and keep livestock in small-scale subsistence farming [10, 16]. Fig. 1 shows the map of Makueni County. Data Collection Climate data for Makueni County was acquired from the Kenya Meteorological Department (KMD). It comprised rainfall and temperature records for 30 years from 1991 to 2020. The data formed by time series of monthly average rainfall recorded in millimeters (mm) as well as the average minimum and maximum monthly temperatures recorded in degrees Celsius (ºC).

Data analysis

Data was presented in tabular and graphic forms and analyzed using descriptive and inferential approaches. Descriptive statistics included frequency summaries, measures of central tendency and measures of dispersion, while inferential statistics involved in trend analysis. The descriptive statistics were used to identify data characteristics and tendencies, while the trend analysis was used to establish any underlying significant patterns, trends, cycles and seasonality in the climate series. The data was collated and analyzed in three sets of time series; monthly, annual-monthly and seasonally. The Mann-Kendall trend test was adopted for identifying significant trends in the precipitation as well as minimum and maximum temperature time series and was conducted at a 5% significance level. The resultant Mann-Kendall Trend Test (*tau*) was used to indicate the magnitude and direction of the trend, *i.e.*, whether positive or negative. The following criteria were used to analyse the hypothesis:

H_0: There does not exist a statistically significant trend, against
H_1: There exists a statistically significant trend (either increasing or decreasing)

Where the computed *p*-value was less than the significance level alpha (α=0.05), the null hypothesis was rejected which implied the presence of a significant trend in the time series while the computed *p*-value was larger than the significant level (α=0.05), the null hypothesis (H_0) failed to be rejected implying the absence of a significant trend in the time series. Significant trends were further described using Ordinary Least Squares (OLS) simple linear regression analysis of time series data. A linear regression was fitted to generate a trend line (1):

$$T = \beta_0 + \beta_1 t \qquad (1)$$

Where: T is the trend value of rainfall amounts (mm), or temperature (°C), β_0 is the y-intercept, and $\beta_1 t$ is the coefficient representing the rate of change of the climate variable over the period. These coefficients were used to estimate the rate of increase/ decrease in the climate (rainfall and temperature) series monthly, annually, and seasonally. The coefficient of determination (R^2) was; however, used to indicate the significance of the trendline equation together with the *p*-value.

Results

Rainfall Trends

Monthly rainfall trends

The monthly climatic data generated a time series of 360 data points. Fig. 2 shows the pattern of monthly rainfall distribution received in the area over 30 years. The rainfall gradually increased in the first 100 months of the study period to reach the highest recorded amount of approximately 490 mm. The levels then decreased steadily over the next 100 months before increasing slightly to approximately 470 mm. Thereafter, the levels oscillated between a low of 0 mm and a high of 350 mm with significant fluctuations. The patterns depict high variation and instability of the rainfall patterns in the Kibwezi East sub-county. The highest amount of rainfall recorded in a month was 490.4 mm, while in some months, no rainfall was received at all (Table 1). The mean rainfall per month was 46.19 mm, with a standard deviation of 71.89 mm, yielding 155.6% variability. This showed that there exists high instability in the time series thus minimizing the possibility of any significant trend for meaningful rainfall forecasts. This was confirmed by the Mann-Kendal test for trend, which yielded a *p*-value of 0.957, which was greater than the significance level of 0.05. This, however, indicates that the trend in the monthly rainfall series was not significant.

Annual-monthly rainfall trends

A rainfall time series of 30 data points were generated for each month by collating the observations corresponding to a month in each year. The time series were analyzed for descriptive statistics yielding the results in Table 2. The months of January, February, March, April, October, November, and December were found to be the wettest months. However, the amounts of rainfall received in these months were associated with high dispersion of 186.2%, 142.3%, 97.7%, 65.4%, 161.9%, 61.2%, and 72.8%, respectively. This implies that the time series were significantly unstable thus not exhibiting any discernible patterns for trend analysis. On the other

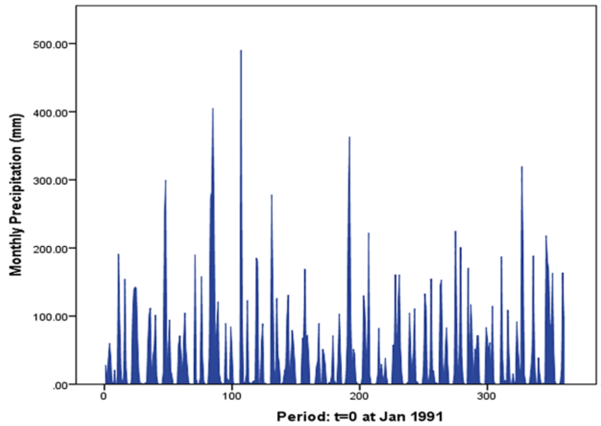

Fig. 2 Monthly rainfall time series for the period January 1991–December 2020.

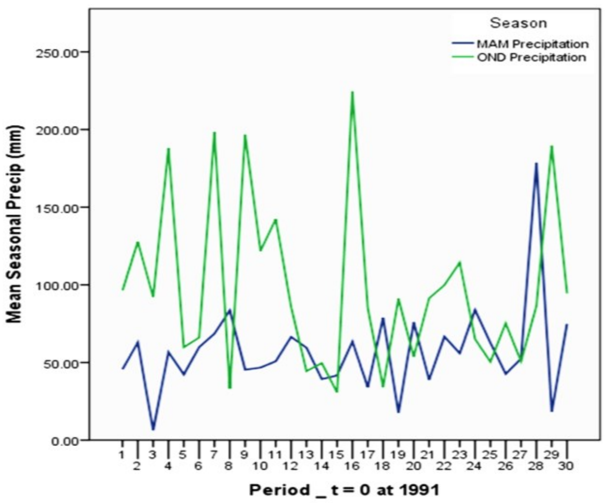

Fig. 3 Line graphs of seasonal rainfall time series for the March-April-May (MAM) and October-November-December (OND) seasons during 1991–2020.

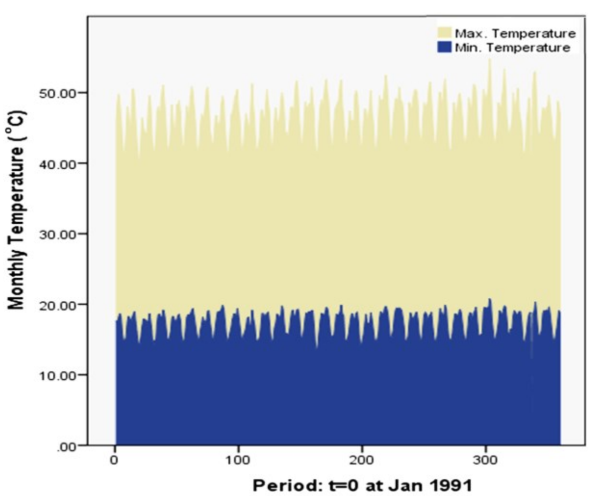

Fig. 4 Monthly minimum and maximum temperature time series (1991–2020).

hand, the driest months over the 30 years were May, June, July, August, and September with the lowest maximum and mean amounts of received rainfall. The means were also associated with high variations of 111.6%, 233.9%, 254.1%, 247.1%, and 421.4%, respectively, eliminating the possibility of any data stability or trend. The time series were further analyzed for annual-monthly rainfall trends yielding the results in Table 2. The *p*-values were found to be greater than the significance level of 0.05, for all months, which led to the failure to reject the null hypothesis for the absence of a significant trend. This implied that the annual monthly rainfall time series did not exhibit any significant trend over the 30 years. The irregular pattern exhibited by the movements in the monthly amounts of rainfall showed the unpredictability of rainfall in this area, the result of which was the absence of a consistent trend that could facilitate projection and/or forecasting. This was confirmed by the tests for trend whose results indicated that there exists no significant trend in the precipitation time series data. Table 2 indicates the descriptive statistics and the Mann-Kendall tests for trend in annual-monthly rainfall time series for the period 1991-2020.

Seasonal rainfall trends

The area of study has two rainy seasons in a year; March-April-May (MAM), and October-November-December (OND). A time series of 30 data points was compiled for each season, by averaging the observations of the three months in a season (Mean) in each year. Fig. 3 shows the line graphs of seasonal rainfall levels during the MAM and OND seasons over 30 years. Generally, precipitation intensity was found to be higher during the OND seasons than the MAM seasons over this region. Further, significant movements were observed in both time series thus reducing the chances of a consistent pattern and meaningful trend analysis. Table 3 shows the descriptive statistics and Mann-Kendal test of trend results for the seasonal rainfall time series over the period 1991-2020. The MAM season precipitation time series recorded a minimum of 6.3 mm and a maximum of 178.6 mm received per month. The mean monthly amount of rainfall in this season was 57.35 mm, with a standard deviation of 29.27 mm, yielding 51% variability. The OND precipitation had the minimum amount of rainfall received as 30.67 mm and the highest as 224.43 mm per month. The mean rainfall was determined as 97.97 mm with a standard deviation of 53.29 mm yielding 54.4% variability. On the other hand, the *p*-values for the

Table 1 Descriptive statistics and the Mann-Kendall test for trend on monthly rainfall time series (1991–2020).

Descriptive statistics		Mann-Kendal test for trend	
N	360	H_0	No significant trend
Minimum	0.00	N	360
Maximum	490.40	*tau*	-0.002
Mean	46.19	*P*-value	0.957
Standard deviation	71.89	Decision	Fail to reject H_0

Table 2 Descriptive statistics of the annual-monthly rainfall time series (1991–2020).

Month	Min.	Max.	Mean	SD	*tau*	*p*-value	Decision
Jan	0	405.2	42.66	79.43	0.023	0.872	Not significant
Feb	0	232.8	34.26	48.76	0.078	0.565	Not significant
Mar	0	319.6	75.62	73.86	0.069	0.605	Not significant
Apr	0.6	201.6	74.02	48.4	0.012	0.943	Not significant
May	0	121.2	22.42	25.03	0.016	0.915	Not significant
Jun	0	19.5	1.89	4.42	-0.083	0.554	Not significant
Jul	0	5.0	0.37	0.94	-0.210	0.152	Not significant
Aug	0	21.2	1.87	4.62	-0.058	0.692	Not significant
Sep	0	170.6	7.25	30.55	0.049	0.737	Not significant
Oct	0	218.4	26.71	43.24	-0.054	0.694	Not significant
Nov	33.6	490.4	151.20	92.57	-0.122	0.354	Not significant
Dec	5.8	363.3	116.00	84.47	-0.044	0.721	Not significant

*Significance level, α=0.05; N=30; SD = standard deviation; *tau* = Mann Kendall trend test

Table 3 Descriptive statistics and the Mann-Kendall test for trend of seasonal rainfall time series (1991–2020).

Descriptive statistics						Mann-Kendal test for trend		
Season	N	Min.	Max.	Mean	Std. dev.	*tau*	*p*-value	Remarks
MAM	30	6.3	178.6	57.35	29.27	0.099	0.454	Not Significant
OND	30	30.67	224.43	97.97	53.29	-0.09	0.498	Not Significant

*Significance level, α=0.05; N=30

seasonal rainfall time series in both seasons were found to be greater than the significance level (0.05). This led to failure to reject the null hypotheses thus the conclusion that the time series did not exhibit statistically significant trends.

Temperature trends

Monthly temperature trends

Minimum and maximum temperature data was collated to generate two-time series of 360 data points each. Fig. 4 shows the patterns exhibited by the monthly maximum and minimum temperature time series over 360 months. Both minimum and maximum temperatures were observed to vary insignificantly within some narrow ranges of 14ºC-18ºC and 25ºC-34ºC, respectively. However, the minimum temperature series appeared more stationary; the maximum temperature series exhibited a gradual increase over the period. Further analysis of the data and testing for any underlying trends yielded the findings in Table 4. The highest maximum temperature observed in a month over 30 years was 34ºC, while the lowest was 25.8ºC. The mean maximum temperature was 29.3ºC with a standard deviation of 1.67ºC, yielding low variance of 5.7%. This indicates high stability of the time series thus high chances of a stable trend, which could be adopted for forecasting. The highest minimum temperature was found to be 20.8ºC, while the lowest minimum temperature was 1ºC. The mean minimum temperature was 17.3ºC with a standard deviation of 1.84ºC, yielding 10.6% variability. The monthly minimum and maximum temperatures yielded *p*-values less than 0.05, thus the null hypothesis was rejected and the two-time series exhibits significant trends. For further assessment of the trends, the line graphs of the two-time series as well as the trend lines and the least square trend line equations were constructed as shown in Fig. 5. The monthly maximum and minimum temperature time series exhibited positive linear trends in which case the maximum temperature increased by 0.003ºC and the minimum temperature increases by 0.001ºC per

Table 4 Descriptive statistics and the Mann-Kendall test for trend on monthly temperature time series (1991–2020).

	Descriptive statistics				Mann-Kendal test for trend		
	Min.	**Max.**	**Mean**	**Standard dev.**	***tau***	***p-value***	***Remarks***
Min. Temperature	1.00	20.80	17.33	1.84	0.093	0.009	Significant
Max. Temperature	25.80	34.00	29.29	1.67	0.120	0.009	Significant

*Significance level, α=0.05; n=360

Table 5 Descriptive statistics and Mann-Kendall tests for trend in annual-monthly temperature time series for the period 1991-2020.

Months	Temperature (ºC)	Min	Max	Mean	SD	*tau*	*p*-value	Remarks
January	Max	26.4	31.6	29.59	1.42	0.273	0.037	Significant
	Min.	1	19.53	17.52	3.14	0.119	0.371	Not significant
February	Max.	27.1	32.7	31.31	1.22	0.081	0.543	Not significant
	Min.	16.9	19.5	18.38	0.67	0.372	0.005	Significant
March	Max.	28.43	34	31.53	1.31	0.190	0.148	Not significant
	Min.	17.8	20.8	19.18	0.61	0.225	0.089	Not significant
April	Max.	27.34	32.66	30.15	0.98	0.177	0.180	Not significant
	Min.	17.7	20.32	18.99	0.54	0.275	0.039	Significant
May	Max.	27	30.7	29.17	0.92	0.072	0.592	Not significant
	Min.	16.4	18.74	17.57	0.53	0.014	0.929	Not significant
June	Max.	26.63	29.3	27.95	0.66	0.310	0.018	Significant
	Min.	14.7	16.58	15.73	0.51	-0.019	0.900	Not significant
July	Max.	25.8	28.76	27.15	0.76	0.350	0.008	Significant
	Min.	13.1	15.9	14.57	0.53	0.092	0.496	Not significant
August	Max.	26.2	28.8	27.63	0.73	0.463	0.000	Significant
	Min.	13.9	16.5	15.11	0.47	0.335	0.013	Significant
September	Max.	27.89	30.3	29.29	0.66	0.338	0.011	Significant
	Min.	14.7	16.7	15.99	0.45	0.220	0.099	Not significant
October	Max.	28.9	31.6	30.46	0.71	0.351	0.007	Significant
	Min.	16.6	19	17.66	0.61	0.317	0.016	Significant
November	Max.	26.8	30.7	28.94	0.93	0.324	0.014	Significant
	Min.	17.9	19.6	18.7	0.41	0.528	0.000	Significant
December	Max.	26	30.3	28.28	1.16	0.295	0.024	Significant
	Min.	17.4	19.5	18.53	0.46	0.420	0.002	Significant

*Significant level, α=0.05; n=30; SD = standard deviation; *tau* = Mann Kendall trend test

month. Though associated with a low coefficient of determination (R^2=3.88%), the maximum temperature trend equation was significant with a *p*-value was <0.000. On the other hand, the coefficient of determination for the minimum temperature trend line equation was quite low (R^2=0.33%) and the *p*-value was 0.275, thus not statistically significant.

Annual-monthly temperature trends

Time series of 30 data points for each month were compiled for minimum and maximum temperatures by picking observations corresponding to a month in each year. Table 5 shows the descriptive statistics of the two-time series. The mean maximum and minimum temperature time series for all months fell within narrow ranges of 27.15ºC-31.53ºC and 14.57ºC-19.18ºC, respectively. March was the hottest month while July was the coldest month over the period. The temperature time series yielded low variability (<10%) indicating the likelihood of underlying significant trends. Mann-Kendall trend tests were done on minimum and maximum temperatures for each month over 30 years. Significant trends were detected in some specific temperature time series in some months. Specifically, significant trends were detected in maximum temperature data for January, June, July, August, September, October, November, and December. Significant trends were also detected in the minimum temperature data series for February, April, August, October, November, and December. The detected trends were analyzed using the least squares regression for time series.

Table 6 shows the least squares trend line equations for the detected trends in the maximum and minimum temperature data series for each month. The detected trends were found to be positive indicating that the temperatures in Kibwezi East sub-county gradually increased over the years. January's maximum temperature was found to be increasing at the highest rate of 0.08ºC annually, followed by December's maximum temperature increasing at

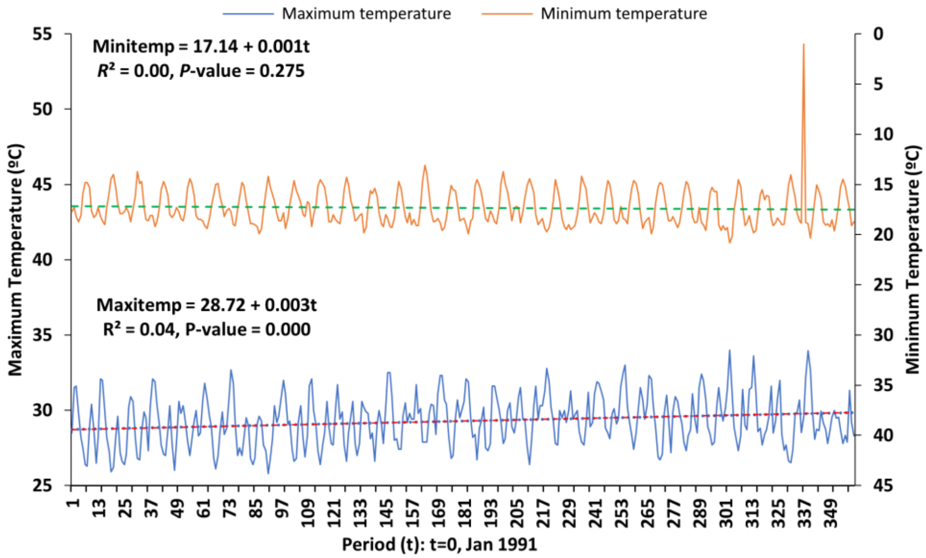

Fig. 5 Monthly minimum and maximum temperature time series (1991–2020).

0.06ºC. Maximum temperature for July, August and November was increased by 0.05ºC, for October increased by 0.04ºC and for June and September increased by 0.03ºC per year. The minimum temperatures for February were increased by 0.04ºC, by 0.03ºC for April, October, November and December, and by 0.02ºC for August per year. Though the trends were associated with R^2 <50%, they were found to be significant with p-values less than the significance level (0.05), except for June, which had the lowest R^2. This trend shows that the temperatures were increasing in the most critical months when the green gram crop was in production. The high temperature at this physiological growth period affects crop and soil moisture levels as well as increases the transpiration rate of the crop leading to decreased production.

Seasonal temperature trends

Temperature time series of 30 data points were compiled for each season. March to May (MAM) and October to December (OND) by averaging the observations of the three months in a season in each year. Fig. 6 shows the movements in the minimum and maximum time series in both MAM and OND seasons over 30 years. Significant movements could be observed in the maximum seasonal temperature data for the MAM seasons, which was significantly higher than the maximum temperature of the OND seasons throughout the 30 years. Moderate movements were, however, observed in the minimum temperatures for both seasons, indicating some stability in the patterns and possible meaningful trends. Descriptive statistical analysis of the seasonal temperature time series for the period 1991–2020 yielded the results in Table 7. The lowest maximum temperature during the MAM seasons was 27.82ºC, while the highest was 32.21ºC. The mean maximum temperature was 30.28ºC with a standard deviation of 0.84ºC, thus 2.8% variance. The lowest minimum temperature of all MAM seasons during the period was 17.63ºC, while the highest was 19.53ºC. The mean was determined as 18.58ºC with a standard deviation of 0.42ºC, thus 2.3% variance. On the other hand, the maximum temperature during the OND seasons had a low of 27.37ºC and a high of

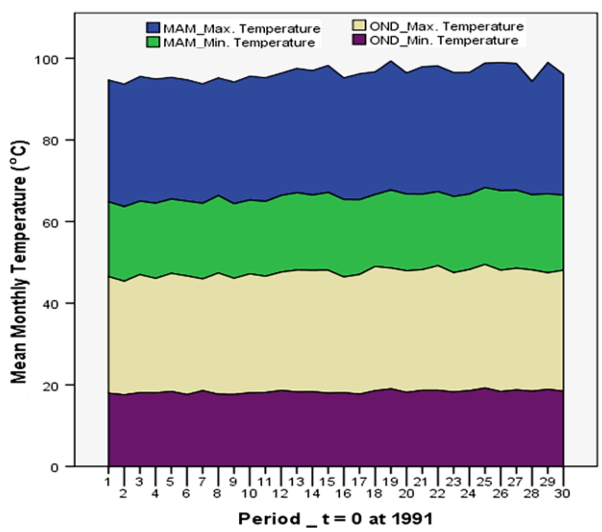

Fig. 6 Seasonal maximum and minimum temperature time series for March-April-May (MAM) and October-November-December (OND) during 1991–2020.

Table 6 Least squares trend equations for maximum and minimum temperature time series for each month.

Month	Trend equation	R^2	*p*-value
January	Max. Temp = 28.39 + 0.08t	0.22	0.018
	Min. Temp = 18.75 - 0.08t	0.05	0.186
February	Max. Temp = 30.89 + 0.03t	0.04	0.272
	Min. Temp = 17.77 + 0.04t	0.26	0.002
March	Max. Temp= 31.04 + 0.03t	0.04	0.074
	Min. Temp= 18.75 + 0.03t	0.16	0.045
April	Min. Temp = 18.58 + 0.03t	0.18	0.019
	Max. Temp = 29.81 + 0.02t	0.037	0.090
June	Max. Temp = 27.53 + 0.03t	0.13	0.054
	Min. Temp = -0.0003t + 15.73	0.00	0.450
July	Max. Temp = 26.41 + 0.05t	0.30	0.002
	Min. Temp = 14.43 + 0.01t	0.02	0.248
August	Max. Temp = 26.81 + 0.05t	0.40	0.000
	Min. Temp = 14.76 + 0.02t	0.18	0.021
September	Max. Temp = 28.84 + 0.03t	0.14	0.038
	Min. Temp= 15.72 + 0.02t	0.11	0.049
October	Max. Temp = 29.88 + 0.04t	0.21	0.011
	Min. Temp = 17.17 + 0.03t	0.21	0.012
November	Max. Temp = 28.1 + 0.05t	0.25	0.005
	Min. Temp = 18.19 + 0.03t	0.50	0.000
December	Max. Temp = 27.3 + 0.06t	0.22	0.008
	Min. Temp = 18.14 + 0.03t	0.23	0.007

*Significance level, α=0.05

Table 7 Seasonal climate trend analysis for the period 1991–2020.

Seasons	Temperature (ºC)	Min	Max	Mean	SD	*tau*	*p*-value	Remarks
MAM	Max.	27.82	32.21	30.28	0.84	0.207	0.116	Not significant
	Min.	17.63	19.53	18.58	0.42	0.321	0.014	Significant
OND	Max.	27.37	30.53	29.23	0.77	0.401	0.002	Significant
	Min.	17.57	19.23	18.30	0.41	0.490	0.000	Significant

* Significance level, α=0.05; N=30; MAM = March-April-May; OND = October-November-December; SD = standard deviation

30.53ºC. The mean maximum temperature was obtained as 29.23ºC with a standard deviation of 0.77ºC and 2.6% variability. The average minimum temperature for the season had a low of 17.57ºC, a high of 19.23ºC, a mean of 18.3ºC and 2.2% variance. The *p*-value for maximum temperature during the MAM seasons was found to be greater than the significance level (0.05) (see Table 7). This led to the failure to reject the null hypothesis; thus, the time series did not exhibit a statistically significant trend. On the other hand, *p*-values for the minimum temperature in both seasons and maximum temperature during the OND season were found to be less than 0.05, thus the null hypothesis was rejected. This implies that these time series exhibited significant trends at a 5% significance level. Fig. 7 shows the time series and trend analysis of the minimum temperature time series data for the MAM season, the least squares trend line and the trend line equation. The MAM seasonal minimum temperature trend line shows a gradual positive trend where the minimum temperature during the MAM seasons increased by 0.02ºC every year. The coefficient of determination associated with the trend line equation was 17.37%, while the *p*-value was 0.022, hence significant. Figure 8 shows the time series and trend analysis for the OND seasonal maximum and minimum temperature data. Generally, gradual positive trends were observed in both OND temperature time series. The maximum temperature was increased by 0.05ºC every year, while the minimum temperature increased by 0.03ºC. The trend line equations are associated with significant coefficients of determination; 33.91% and 40.06%, and *p*-values < 0.05; 0.0007 and 0.0002, respectively, implying that the trend equations were statistically significant**.** The positive nature of the temperature trends indicated a gradual rise in temperature levels over the years, clear evidence of climate change.

Discussion

The patterns in the monthly rainfall series depicted high variation and instability of the rainfall patterns in the Kibwezi East sub-county. The highest amount of rainfall recorded in a month was 490.4 mm, with

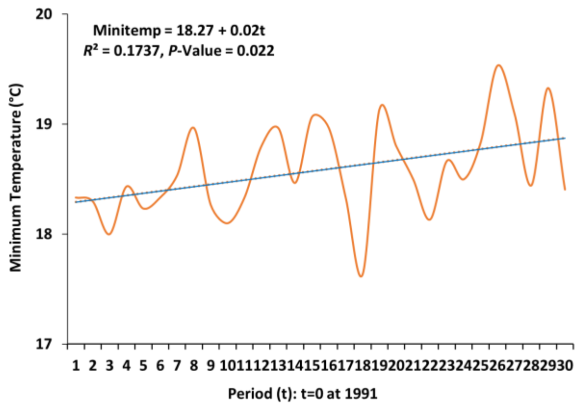

Fig. 7 March-April-May (MAM) seasonal minimum temperature time series for the period 1991–2020.

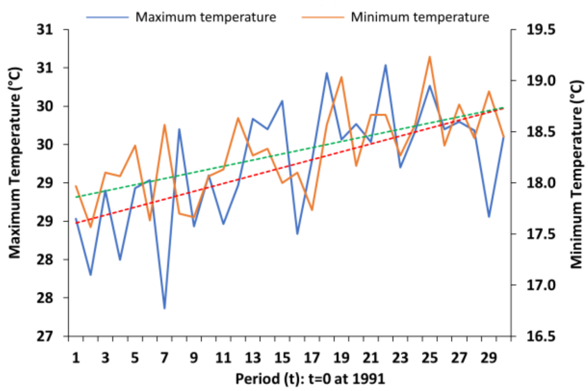

Fig. 8 October-November-December (OND) seasonal maximum and minimum temperature time series: 1991–2020.

some months recording no rain. There was a clear indication of high rainfall variability and instability in the time series which minimized the possibility of any significant trend for meaningful rainfall forecasts. The results obtained agree with a study done by Recha et al. [17], which showed that there was increased variability in rainfall in the arid and semi-arid areas of Kenya and the average total annual rainfall amounts decreased over the last 50 years. Nzisa, [18] while studying the contribution of ecosystem services to livelihoods in the Kibwezi sub-county also found that rainfall is unreliable for food crop production and permanent rivers are the only potential sources for irrigation. Similarly, Omoyo et al. [19] found that variations in rainfall, temperature and evaporation tend to have remarkable effects on maize yields over lower eastern Kenya, and that rainfall amounts decreased by 3 mm per annum depicting the high variation and instability of the rainfall in the study area.

Precipitation intensity was also found to be higher during the OND season than the MAM season with significant movements observed in both time series thus reducing the chances of a consistent pattern and meaningful trend analysis. Similar observations were made by Recha et al. [17] who found that the Makindu area in Makueni County had more rainy days in the OND rains as compared to the MAM and that more seasons exhibited low rainfall amounts as opposed to those with high rainfall. They further reported that the number of rainy days in the MAM season had gradually decreased and were not able to support a crop to maturity. Similarly, Amukono et al. [20] while studying agroclimatic characterization of Makueni county using rainfall data found that the county has a low probability of wet days with Mbooni having the highest probability of 48% with OND season being its best season with 60% of the total annual rainfall. These results were from a study done by Herrero et al. [21]. The study analyzed season-to-season rainfall variability in the Makindu area from 1959-2004 and found that there was great variability in the rainfall totals and no statistically significant trend was detectable from the rainfall data. However, rainfall variability of this magnitude affects agricultural production as well as people's livelihoods [22]. The problem of unpredictability of the climatic conditions worsens the plight of farmers who rely on rain-fed farming. Specifically, rainfall instability which is discernible in the MAM as well as the OND season, in the absence of water sources for irrigation, renders consistent productive agriculture unattainable in this area.

Both minimum and maximum temperatures were observed to vary insignificantly within some narrow ranges of 14ºC-18ºC and 25ºC-34ºC, respectively, with the minimum temperature being stationary while the maximum temperature exhibited a gradual increase over the period. However, the monthly minimum and maximum temperatures had positive significant trends in which the maximum temperature was increased by 0.003°C and the minimum temperature increased by 0.001°C per month. The mean annual maximum and minimum temperature time series for all months fell within narrow ranges of 27.15ºC-31.53ºC and 14.57ºC-19.18ºC, respectively. March was the hottest month while July was the coldest month over the period. The detected trends in the series were found to be positive indicating that the temperatures in Kibwezi East sub-county gradually increased over the years. This trend shows that the temperatures were increasing in the most critical months when the green gram crop was in production. High temperatures at this physiological growth period and the crop must affect the soil moisture levels as

well as increasing the transpiration rate of the crop leading to decreased production. These results agree with the reports of Makokha and Shisanya [23], who while studying trends in mean annual minimum and maximum surface temperature in Nairobi city found that the change of temperature over the entire study period was higher for minimum temperature than maximum temperature and that the annual minimum air temperature is shown to have higher rates of change and also higher compared to the annual maximum air temperature. The rates of change of temperature were higher for suburban stations compared to urban stations, an indication of increasing urban sprawl. Significant movements were also observed in the maximum seasonal temperature data for the MAM seasons, which was significantly higher than the maximum temperature of the OND seasons throughout 30 years. Moderate movements were, however, observed in the minimum temperatures for both seasons, indicating some stability in the patterns and possible meaningful trends. The lowest maximum temperature during the MAM seasons was 27.82ºC, while the highest was 32.21ºC. The mean maximum temperature was 30.28ºC with a standard deviation of 0.84ºC, thus 2.8% variance. The lowest minimum temperature of all MAM seasons during the period was 17.63ºC, while the highest was 19.53ºC. The mean was determined as 18.58ºC with a standard deviation of 0.42ºC, thus 2.3% variance. On the other hand, the maximum temperature during the OND seasons had a low of 27.37ºC and a high of 30.53ºC. The mean maximum temperature was obtained as 29.23ºC with a standard deviation of 0.77ºC and 2.6% variability. The average minimum temperature for the season had a low of 17.57ºC, a high of 19.23ºC, a mean of 18.3ºC and 2.2% variance. However, the trends were insignificant during the MAM season for maximum temperature. During OND, both maximum and minimum temperatures had significant increasing trends. Generally, gradual positive trends were observed in both OND temperature time series. The maximum temperature was increased by 0.05ºC every year, while the minimum temperature increases by 0.03ºC. The trend line equations are associated with significant coefficients of determination; 33.91% and 40.06%, and p-values of 0.0007 and 0.0002, respectively, implying that the trend equations were statistically significant**.** The positive nature of the temperature trends indicates a gradual rise in temperature levels over the years, clear evidence of climate change. In conclusion, the average monthly rainfall amount was found to be 46.19 mm with high variability (standard deviation) of 71.89 mm. The average monthly minimum and maximum temperature levels were 17.33ºC and 29.29ºC, respectively. The temperature data was associated with low variability with standard deviations of 1.84ºC and 1.67ºC, respectively. The analysis revealed that the minimum monthly temperature increased by 0.001ºC per month, while the maximum monthly temperature increased by 0.003ºC per month. This analysis showed very high average monthly temperatures as well as very low average monthly rainfall amounts. The months of January, February, March, April, October, November and December were found to be the wettest months. These months fall within the two rainy seasons that are experienced in the area. However, the amounts of rainfall received in these months were associated with high dispersion of 186.2%, 142.3%, 97.7%, 65.4%, 161.9%, 61.2% and 72.8%, respectively. This implies that the time series were significantly unstable thus not exhibiting any discernible patterns for trend analysis. On the other hand, the driest months over 30 years were May, June, July, August and September with the lowest maximum and mean amounts of received rainfall. The means were also associated with high variance of 111.6%, 233.9%, 254.1%, 247.1% and 421.4%, respectively, eliminating the possibility of any data stability or trend. The annual-monthly minimum temperature data showed significant trends in February, April, August, October, November and December, while the annual-monthly maximum temperatures showed significant trends in January, June, August, September, October, November and December. These findings agree with the IPCC [24] and McCarthy et al. [25] who predicted that the temperature will rise by 0.2 degrees centigrade per decade in Kenya. These reports also state that trends of weather and climate events are increasingly deviating from normal which can be linked to the continuing global warming and climate change which is seen to be evident in the region. This raises concerns regarding sustainable green gram farming for food security in the region, due to these unfavorable climatic conditions, specifically, the high and increasing temperatures, and inconsistent and unpredictable rainfall.

Generally, precipitation intensity was found to be higher during the OND seasons than during the MAM seasons. Whereas the minimum and maximum temperatures were higher in the MAM season than in the OND. This makes the MAM season very unsuitable for a wide range of crops like green grams, cowpeas and others that are grown in semi-arid areas.

The MAM season precipitation time series recorded a minimum of 6.3 mm and a maximum of 178.6 mm received per month. The OND precipitation had a minimum of 30.67 mm and the highest was 224.43 mm per month. The seasonal minimum temperature data had a mean of 18.58°C and 18.3°C in the MAM and OND seasons, respectively. On the other hand, the seasonal maximum temperature data had means of 30.28°C and 29.23°C in the two seasons, respectively. The minimum temperature increased by 0.02°C per annum and 0.03°C per annum in the MAM and OND seasons, respectively, while the maximum temperature increased by 0.05°C per annum in the OND season**.** These results agree with a study done by Wamuongo [26] of temperature and rainfall for a 30-year period for Machakos County which is a neighboring county, which showed high year-to-year variation in annual mean minimum and maximum temperatures. There was an increase in maximum temperature by one-degree centigrade and 0.3°C for minimum temperature, which is consistent with the IPCC fourth assessment report temperature projections for Easter Africa [27].

According to Stober et al. [28], lack of rainfall and extreme heat conditions can cause wilting of crops as well as attract diseases and pests, therefore, reducing yields. This was confirmed by Datta [29], who observed that extreme weather may induce certain crop diseases, like rust which is more prevalent in warm weather conditions. Abang et al. [30] confirmed that insect pest attack is higher during the dry season like in the case of Aphids in green grams, whereas disease attack like the case of Downey mildew in green grams is more problematic during the rainy season. Similarly, Gregory et al. [31] noted that climate change was affecting the distribution of plant pests, diseases and weeds. Plant diseases, pests and weeds are critical factors to consider in crop production. They have a direct impact on crop yields and agricultural production globally. Further, climate change aggravates the situation on the occurrence and severity of diseases and pests which are a serious threat to food security [32, 33].

Conclusions

With the observations made from the study, it is important to note that the temperatures were increasing. The events of high temperatures and the variable rainfall conditions lead to decreased yields due to attacks by emerging crop pests and diseases, poor pod filling, high evapotranspiration and reduced moisture levels. Green gram is a crop that is adapted to high temperature conditions of 28°C to 30°C conditions with rainfall amounts ranging from 350 mm-650 mm. The crop also requires rainfall to be well distributed throughout the season and favorable temperature conditions, especially at the sensitive phonological stages of germination, active vegetative growth, pollination and grain filling. Farmers are in dire need of adaptation strategies and farming techniques that build resilience towards harsh climatic conditions. This can have severe socio-economic impacts such as food insecurity, economic instability, severe malnutrition, school dropouts, household conflicts and in general poor living standards. There are various adaptive responses available to deal with unpredictable weather conditions which are climate smart. These include technological options such as planting improved seed varieties of green grams, early planting, crop rotation, timely weed, pest and disease control and soil nutrition replenishment, as well as soil and water management practices. Further, farmers cannot continue with business-as-usual scenarios. They need resources and skill-based support to enable them to afford and implement innovative climate-smart farming techniques.

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Conflict of interest

The authors declare that they have no conflict of interest.

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